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TITLE: COMPOSITION AND METHOD OF FORMING ALUMINUM ALLOY FOIL

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COMPOSITION AND METHOD OF FORMING ALUMINUM ALLOY FOIL

BACKGROUND OF THE INVENTION

The present invention describes a method of forming an aluminum alloy foil suitable for continuous casting in the fabrication of fins used in brazed automotive heat exchangers.

Aluminum foil is the preferred choice for forming fins used in heat transfer and air conditioning equipment such as radiators, condensers, oil coolers and evaporators. A preferred choice of alloy for this application, particularly in automobile heat exchangers, is the alloy AA 3003. It has the composition shown in Table I below:

TABLE I

Elements	Wt.%
Silicon	0.6 max
Iron	0.7 max
Copper	0.05-0.20%
Manganese	1.0-1.5
Zinc	0.10 max
Balance aluminum (including unavoidable impurities)	

In another version of this alloy, Zn is also added to it when the fin is used in the sacrificial mode. The concentration of Zn can vary between 0.5 to 2%.

The aluminum foil is usually in the thickness range of 0.002-0.008 in. An aluminum sheet is cold rolled to this final gauge starting from a reroll sheet that is in the gauge range of 0.04-0.3 in. The reroll sheet is produced by casting DC ingots, homogenizing at elevated temperatures, and then hot rolling to the reroll gauge. Alternatively, the reroll sheet is produced by a continuous casting process and is directly hot or warm rolled to the final reroll gauge. The continuous casting process is advantageous because it is more productive and less expensive.

The radiators, evaporators and other heat exchangers are produced by brazing aluminum fins to the clad aluminum sheet of different shapes or forms. The brazing operation takes place at around 600°C. At this temperature aluminum fins can sag and collapse or, in some cases, affect the crushing pressure that the finished units can take at ambient and operating temperatures. The tendency to sag

during brazing cycle is measured by a property that is characterized as sag resistance. It is generally accepted that higher sag resistance improves performance of the unit. Sag resistance in general is dependent upon the post braze grain size of the aluminum foil. Higher grain size produces higher sag resistance. Therefore, higher grain size (>100 micron in transverse and longitudinal directions) after annealing the sheet is preferred in automotive fin applications.

Alloy 3003, particularly produced by continuous casting method, such as by a belt caster, yields significantly higher grain size than that produced from a corresponding hot rolled and homogenized DC material. The aluminum sheet can be used in the fin forming operation in different tempers, such as from fully hard to fully annealed.

As stated before, alloy 3003 produced by continuous casting is an excellent choice for auto-fin applications because it yields high post braze strength and sag resistance. However, because it contains high amount of Mn and Cu, it gets easily work hardened and is therefore

difficult to roll. Further, during belt casting operation it yields a highly convex profile (>0.6% crown) because it causes high temperature differences between the center and edge of the sheet. This is due to the high Mn and Fe content of the alloy. The convex profile causes problems during rolling and the slitting operations that follow after rolling. As a result, the cost of production of continuous cast 3003 is rather high.

Previous attempts have been made to develop aluminum alloy based aluminum foils. For example, U.S. Patent No. 4,906,534 (Bekki) discusses a method of preparing thin aluminum plates used as fins of heat exchangers from an aluminum alloy core material, comprising 0.6 to 2.0 wt % of Mn, 0.3 wt % or less of Fe, 0.05 to 0.6 wt % of Si, 0.5 to 2.0 wt % of Zn, 0.05 to 0.2 wt % of Cu, and a balance of Al. The patent additionally contemplates use of skin materials of an Al-Si system or an Al-Si-Mg system for cladding the surfaces of the core material.

U.S. Patent No. 4,334,935 (Morris) discloses a fine grained, formable Al-Mn alloy sheet used to make rigid foil

containers. The alloy consists essentially of 1.3-2.3% Mn, up to 0.5% each of Fe, Mg, and Cu, up to 0.3% Si, up to 2.0 % Zn, less than 0.1% each of Zr, Cr, and Ti, other elements up to 0.3% each and up to 1.0% total.

U.S. Patent No. 5,888,320 (Dorward) describes a method of producing aircraft and automobile panels. The product includes an aluminum base alloy consisting essentially of about 0.6 to 1.4 wt. % silicon, not more than about 0.5 wt. % iron, not more than about 0.6 wt. % copper, about 0.6 to 1.4 wt. % magnesium, about 0.4 to 1.4 wt. % Zn, at least one element selected from the group consisting of about 0.2 to 0.8 wt. % manganese and about 0.05 to 0.3 wt. % chromium.

U.S. Patent No. 5,725,695 (Ward) discloses an aluminum foil product made from an aluminum-silicon-iron aluminum alloy consisting essentially of 0.30-1.1% Si, 0.40-1.0% Fe, max 0.10% Cu, max 0.10% Mn, max 0.05% Mg, max 0.05% Cr, max 0.10% Zn, and max 0.08% Ti.

U.S. Patent No. 4,169,728 (Takeuchi) discloses an alloy for die-casting which consists essentially of 0.5-2.5% Zn, 1.1 to 3.0% Mg, 0.3 to 1.2% Si, 0.2 to 1.5% Fe, 0.3 to 1.2% Mn, and 0.1 to 0.3% Cu.

The disclosures of the foregoing references are incorporated by reference into this application in their entirety.

SUMMARY OF THE INVENTION

The disadvantages of prior methods and alloys may be overcome by the present invention, which provides an aluminum alloy foil for fins used in heat exchangers. The improved alloy composition of the present invention consists essentially of about 0.25% to about 0.6% by weight of Si, about 0.15% to about 0.50% by weight of Fe, about 0.20% to about 0.70% by weight of Mn, less than about 0.05% Cu, and less than about 0.05% Mg with the balance aluminum including unavoidable impurities. The alloy composition may also contain less than 0.10% Zn or an amount of Zn in the range from about 0.50 to 2.00% by weight.

The invention also provides a method for making an improved aluminum foil. The method comprises providing a molten aluminum foil alloy having the composition stated in the previous paragraph. The molten alloy is continuously cast into an aluminum alloy strip from the molten aluminum alloy, and cold rolled into a final gauge of between about .002-.008 inches.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides two new alloy compositions, one with Zn and one without Zn. The improved alloy has lower density, reduced manganese levels, and larger grain size to improve sag resistance. The preferred composition ranges for the aluminum alloy in accordance with the present invention is shown in Table II, below:

TABLE II

Composition A	
Elements	**Wt.%**
Silicon	0.25-0.60
Iron	0.15-0.50
Manganese	0.20-0.70
Copper	<0.05
Magnesium	<0.05
Zinc	<0.10
Balance aluminum (including unavoidable impurities)	

Composition B	
Elements	**Wt. %**
Silicon	0.25-0.60
Iron	0.15-0.50
Manganese	0.20-0.70
Copper	<0.05
Magnesium	<0.05
Zinc	0.50 to 2.00
Balance aluminum (including unavoidable impurities)	

The alloy of the present invention has a lower density than DC cast 3003. This reduces the cost of using the alloy as fin stock in brazed heat exchangers where surface area is the determining factor.

In a preferred embodiment of the invention, Si content ranges between about 0.3 and about 0.5%. Silicon and intermetallic particles of silicon, iron and aluminum precipitate in the sheet, making the surface hard. This reduces smut (reaction product) formation during cold rolling. Si above 0.6% is not desired because it makes the scrap less compatible with can scrap and therefore less desirable. Additionally, the amount of silicon present affects the smut generated during cold rolling. As it exceeds a critical level of 0.25%, smut generation decreases significantly. This is because of precipitation of silicon and intermetallic particles of silicon within the matrix that increase the hardness of the metal and thereby reduce the smut generated during cold rolling.

In a preferred embodiment of the present invention, Fe content ranges between about 0.15 and about 0.35%. Low Fe helps increase grain size of the alloy after annealing because it reduces the amount of iron aluminide and iron silicon aluminide particles which pin grains and reduce grain size. Very low Fe is also undesirable as it can affect the total Fe + Mn content in the alloy. The Fe + Mn

content needs to be controlled within desired limits, for reasons explained below.

The reduced manganese levels of the alloy of the present invention accommodate a different strengthening mechanism compared to DC cast 3003. In DC cast 3003, the Mn precipitates out during the hot rolling/homogenizing steps and the precipitates harden the metal. In the present alloy, the Mn stays in solution and provides a solution strengthening effect. For the composition ranges of the present invention, solution strengthening is more effective at producing a strong final product than precipitation hardening.

In a preferred embodiment of the invention, Mn content ranges between about 0.30 and about 0.60%. Reducing Mn from the level present in 3003 reduces the required amount of work hardening during cold rolling, and thereby helps improve cold rolling productivity. The lower limit for Mn is necessary because below this level the grain size after annealing decreases to the level at which it can affect the sag resistance.

The optimal grain size for this application is larger than normal. Generally, small grains are preferred for a good combination of formability and strength. In this application, however, sag resistance is more important and larger grain sizes improve sag resistance.

In a preferred embodiment of the present invention, Mn + Fe content is 0.40%-0.80%. The lower limit is necessary because below this level the shrinkage during casting increases to such an extent that it affects the heat transfer during casting and therefore results in poor surface of the reroll. Poor reroll surface can result in surface cracks in the alloy. The center to edge temperature difference during casting is correlated to the amount of Mn + Fe in the alloy. When the amount of Mn + Fe increases, the temperature difference between center and edge also increases. This results in poor profile during hot rolling, which in turn causes problems during cold rolling and slitting.

In a preferred embodiment of the present invention, Cu content is <0.05%. Copper content of the alloy is minimized

because copper results in work hardening during cold rolling.

The alloys of the present invention are continuously cast to form an as-cast strip 30mm (1.18 inches) or less in thickness. The alloys are preferably cast using twin belt casting, block casting or twin roll casting. In all cases the cast strip is not homogenized prior to subsequent rolling. The as-cast strip may be optionally hot or warm rolled prior to cold rolling or may be directly cold rolled. Warm rolling is carried out at a temperature low enough to avoid recrystallization.

Interanneal during cold rolling is carried out at a gauge such that the cold work after interanneal is between 30-70%. This results in large post braze grain size. The lower limit is necessary as below this level rolling speed in the final pass can decrease significantly.

The composition of the alloy is chosen such that it optimizes performance during casting and rolling to obtain the best combination of post braze properties. Mn and Fe

are two elements that affect casting performance significantly. Aluminum shrinks during casting. To compensate for this shrinkage, the casting gap is reduced from the starting to the finishing point. However, composition of individual alloys can also affect the amount of shrinkage. Two elements that can reduce the amount of shrinkage are Mn and Fe. Reduced shrinkage results in increased heat transfer during casting and therefore yields excellent surface after rolling. Too low a shrinkage can result in increased transverse temperature difference which in turn leads to poor profile after warm rolling. The two must be optimized to give a satisfactory surface and profile.

Another aspect of this invention is the control of post braze grain size. We have discovered that grain size increases with increasing Mn and decreases with increasing Fe. Accordingly, the two must be optimized while respecting limits for improved casting performance. The invention also provides another mechanism for controlling grain size: the alloy is cold worked before brazing to increase the post braze grain size.

The present invention results in better rolling productivity, improved profile, and density of aluminum reduced by about one percent, which yields more feet of sheet for the same weight and thereby improves productivity for the user. There could also be uses for the present invention in other sheet or foil applications.

It is to be understood that the invention is not limited to the features and embodiments set forth above but may be carried out in other ways without departure from its scope and spirit. Accordingly, it is intended that the present invention be limited only by the following claims.